ENSURING THE CORRECT OPERATION OF DISTRIBUTION AUTOMATION SYSTEMS

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ABSTRACT

State of the art distribution automation systems (DAS) are complex, communications based systems requiring high-speed messages exchanged between multifunctional IEDs located at different sites in the distribution system. Ensuring the correct operation of the DAS requires good understanding of its functionality, as well as the use of proper testing methods and tools.

INTRODUCTION

Functional and application testing is the most widely accepted testing practice for protection and control systems and is required to ensure that a Distribution Automation System (DAS) and each of its components are going to operate as designed under different system conditions. This is especially challenging in the cases when Distributed Energy Resources (DER) are connected to the distribution system.

The paper discusses in detail the requirements for functional testing of devices and distributed functions used in DAS. The methods for testing of both types of systems are proposed.

Distribution Automation Systems (DAS) play a very important role in ensuring the quality of power during events at the distribution system. They may cover in some cases geographical areas of different sizes and use high speed communications between multifunctional protection Intelligent Electronic Devices (PIEDs) that perform different functions within the DAS.

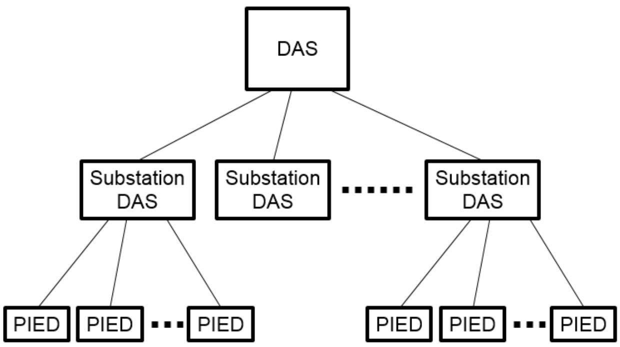

Fig.1 DAS hierarchy

Failure of a DAS to operate when needed or misoperation under non-critical system conditions may have a significant impact on the power quality of the system or result in the unnecessary tripping of multiple loads, in both cases leading to economic losses. That is why it is so important to ensure the correct operation of DAS using proper testing methods and technologies.

The integration of different multifunctional devices in complex DAS distributed over an area requires the use of a standard protocol that will meet the requirements for high speed and reliability necessary to execute protection and distribution automation functions over the wide area network. The assumption at the start of the DAS testing process is that all devices selected for use are compliant with the selected communications protocol and can interoperate with each other in case of use of devices from different manufacturers. The paper discusses in detail the requirements for functional testing of devices and distributed functions used in DAS. The methods for testing of both types of systems are proposed based on the following order of system components tests:

- Functional testing of individual IEDs used in the system
- Functional testing of distributed functions within a substation
- Functional testing of distributed functions between substations
- Functional testing of complete DAS
- End-to-end testing of DAS

The methods for testing of components of the system, as well as the system as a whole are:

- Black box testing
- White box testing
- Bottom-up testing
- Top-down testing

The use of each of these methods for the different types of tests is described in the paper. Solutions for the testing of the individual devices, as well as for the testing of distributed applications are described in detail. Once a DAS is put in service, it is important to ensure that it will not misoperate if there are any problems in any of the components of the system.

FUNCTIONAL TESTING OF DAS

Functional testing is the most widely accepted practice for protection and control systems and is required to ensure that the DAS and each of its components are going to operate as designed under different system conditions.

Understanding what has or hasn't been tested in a complex system is still a major challenge for many organizations, and the time commitment required for quality assurance functional testing needs to become increasingly one of the greatest concerns for ensuring the successful operation of the DAS.

With functional testing the engineering, commissioning and maintenance teams translate functional requirements into executable test cases that confirm how well the DAS satisfies the requirements at any given time or under any specific conditions. A test plan needs to be developed in order to build a suite of executable tests that define and verify the functionality requirements, providing a fast and objective way to assess the performance of the tested functionality. These tests can then be executed regularly to ensure that functional modifications or firmware upgrades do not unintentionally change previously verified functionality.

An effective functional testing practice involves the definition of guidelines for using functional testing technologies effectively, and then the implementation and integration of those guidelines into the asset management system.

To achieve effective system testing, the user or manufacturer must not only have a defined practice for its use, but that practice must be implemented and integrated into the engineering process so that it can be used consistently and regularly across the organization. The definition of the functional tests should be part of the design of the DAS. At the time when the functionality of every single elements of the DAS is designed, it must be specified how it is going to be tested.

The following sections discuss different methods for functional testing of DAS and their individual components as a function of the type of test being performed. They include some definitions of the types and methods to be used for functional and application testing. Since we are testing a complex DAS, it is clear that methods and tools for System Testing will need to be used.

System testing is testing conducted on a complete, integrated system to evaluate the system's compliance with its specified requirements.

As a rule, system testing takes, as its input, all of the "integrated" components that have successfully passed integration testing and also the software system itself integrated with any applicable hardware system(s).

System testing is actually done to the entire system against the Functional Requirement Specification(s) (FRS) and/or the System Requirement Specification (SRS). Moreover, the system testing is a testing phase, where the focus is to test not only the design, but also the behavior and the expected performance of the DAS. It is also intended to test up to and beyond the definitions in the requirements specification(s).

FUNCTIONAL TESTING METHODS

Functional testing methods can be divided into several categories. They are related to the complexity of the functionality of the individual devices being used in the different levels of the hierarchical system, as well as the types of distributed functions implemented in it.

From this point of view the following are the more commonly used testing methods:

- Functional element testing
- Integration testing
- Function testing
- System testing

A function in this case can be considered as a sub-system with different level of complexity, for example a system monitoring (SM) function, while the system is the complete redundant DAS.

Regardless of what is being tested, the test object needs to meet the requirement for testability. This is a design characteristic which allows the status (operable, inoperable, or degraded) of a system or any of its sub-systems to be confidently determined in a timely fashion. Testability attempts to qualify those attributes of system design which facilitate detection and isolation of faults that affect system performance. From the point of view of testability a functional element in a DAS is the unit that can be tested, because it is the smallest element that can exist by itself and exchange information with its peers in the DAS.

Another consideration is the purpose of the test and needs to clarify if the tests are performed in relation to acceptance of a new product or function to be used as a system monitor or process controller (or both), the engineering and commissioning of a substation component or the complete DAS or its maintenance. From that perspective different testing methods can be implemented even in the testing of the same functional element or function.

For example the testing of a system monitoring function during the user acceptance phase may focus on the testing of the measuring element characteristic using search test methods, while during the commissioning the operating times for different system conditions be the important ones achieved through transient simulation methods.

The knowledge of the internal behavior of the test object or more specifically the logic or algorithms implemented determine how the tests are being executed. The most commonly used test methods from this point of view are:

- Black box testing
- White box testing

An important aspect that needs to be considered during the testing is the availability of redundant devices performing the different DAS functions.

The following sections discuss in more detail the different testing methods listed above.

Black box testing

Black Box Testing is a very commonly used test method where the tester views the test object as a black box. This means that we are not interested in the internal behavior and structure of the tested function.

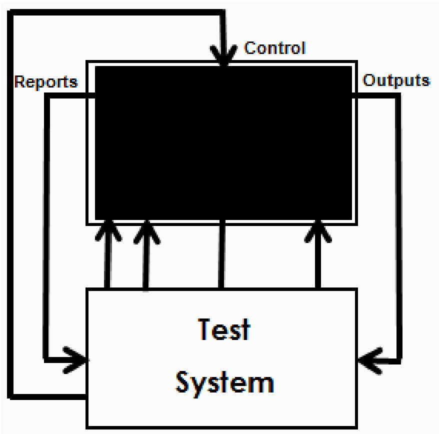

Fig. 2 Black Box Testing

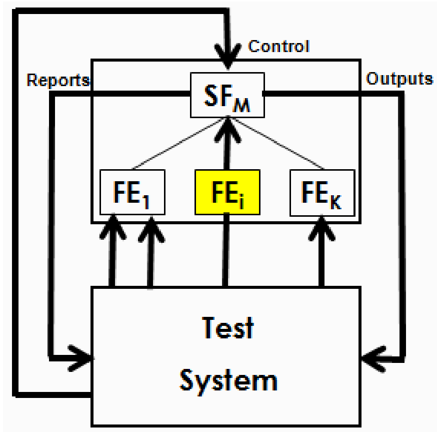

Fig. 3 White box Testing

In the case of black box testing the test system is only interested in finding conditions under which the test object does not behave according to its specifications. Test data are derived solely from the specifications without taking advantage of knowledge of the internal structure of the function.

Black box testing is typically used for:

- functional elements testing
- DAS factory testing
- DAS site acceptance testing

Since functional elements are defined as units that are the smallest that can exist independently and are testable, it is clear that black box testing is the only method that can be used for their testing.

The response of the test object to the stimuli can be monitored by the test system using the operation of physical outputs, communications messages or reports.

White box testing

White box testing is a method where the test system is not only concerned with the operation of the test object under the test conditions, but also views its internal behavior and structure.

In the case of DAS it means that it will not only monitor the operation of the system at its function boundary, but also monitor the exchange of signals between different components of the system.

The testing strategy allows us to examine the internal structure of the test object and is very useful in the case of analysis of the behavior of the test object, especially when the test failed.

In using this strategy, the test system derives test data from examination of the test object's logic without neglecting the requirements in the specification. The goal of this test method is to achieve high test coverage through examination of the operation of different components of a complex function and the exchange of signals or messages between them under the test conditions.

This method is especially useful when we are testing distributed functions based on different logical interfaces. The observation of the behavior of the sub-functions or functional elements is achieved by the test system through monitoring of the exchange of messages between the components of the test object.

The test scenarios however do not have to be different from the ones used under black box testing.

Top-down testing

Top-down testing is a method that can be widely used for DAS, especially during site acceptance testing, when we can assume that all the components of the system have already been configured and tested.

Top-down testing can be performed using both a black box and a white box testing method.

The testing starts with the complete system, followed by function or sub-function testing and if necessary functional element testing.

In the case of factory acceptance testing, when not all components of a system or sub-system are available, it is necessary for the test system to be able to simulate their operation as expected under the test scenario conditions. In this case the test system creates the so called Stubs for functions or functional elements that are not yet available.

Top-down testing results in re-testing of higher level elements when additional lower level elements of the system are added. The adding of new elements one by one should not be taken too literarily. Sometimes a collection of elements will be included simultaneously, and the whole set of elements will serve as test harness for each functional element test.

Each functional element is tested according to a functional element test plan, with a top-down strategy.

A testing stub is a module which simulates the operations of a module which is invoked within a test. The testing stub can replace the real module (for example a line monitor) for testing purposes.

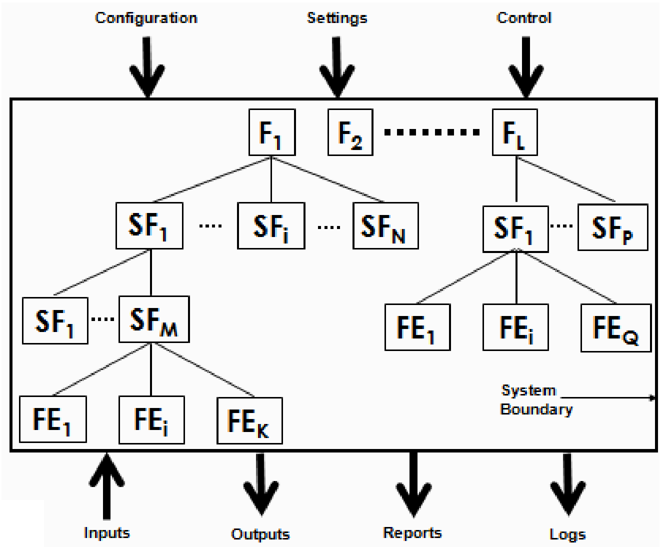

Fig. 4 Top-down testing of distribution automation system

If we consider a DAS implementation in IEC 61850 for testing using a top-down approach, we will start with the definition of the function boundary.
The testing of the individual components of a system function might be required in the case of failure of a specific test, which is shown in Fig. 4. The function boundary for each of these tests will be different and will require a different set of stimuli from the test system, as well as the monitoring of the behavior of the functional elements using different signals or communications messages.
For example, if the detection of a change of state of a monitored line fails and we perform further test down the function hierarchy as shown in Fig. 4, and still get a failure, we may have to perform tests at the bottom of the hierarchy, including testing of functional elements of some monitoring function such as the measurements of distribution feeder currents or active power represented by logical nodes MMXU.

Bottom-up testing

Bottom-up testing is a method that starts with lower level functions – typically with the functional elements used in the system.
This method is more suitable for type testing by a manufacturer or acceptance testing by the user.
When testing complex multilevel functions or systems, driver functional elements must be created for the ones not available. The test system must be able to simulate any missing component of the system when performing for example factory acceptance testing.
There are many similarities in the test scenarios used in the bottom-up, compared to the top-down method. The main difference between the two methods is the order that the tests are performed and the number of tests required.

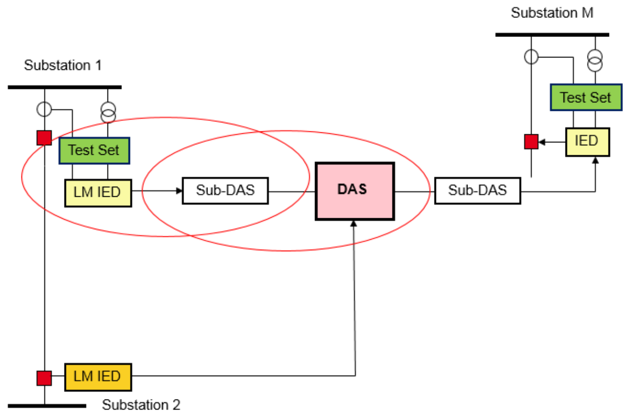

Fig. 5 Integration test

Integration Test

Integration test is used to ensure that the individual components of the system not only interoperate correctly, but also meet the performance requirements according to the DAS development specification.
In this case they will include testing of devices at two ends of a communications link. The methods and tools used are in the category of end-to-end and sub-system testing as described earlier.

DAS Factory Acceptance Test (FAT)

The factory acceptance test (FAT) is a customer agreed functional tests of the specifically designed and implemented DAS. It is a subject of agreement between the final user and the system integrator and is highly recommended, since it allows the detection of potential problems in an earlier stage of the project, when it is less expensive and easier to fix them.
Factory acceptance testing should be performed using a top-down approach based on a test plan including test scenarios defined as part of the design of the system.
Black box testing methods can be used until any failure of the system for a specific test occurs. White box testing will then be used to determine the reason for the test failure.
One of the characteristics of factory acceptance testing is that not all components of the system are available. That requires from the test system the ability to simulate devices missing from the factory system, which is a part of the real DAS.
Another differentiating factor for the FAT is that all existing components of the system are configured and set according to the requirements of the real system application.
The factory acceptance test thus should be based on configuration of all devices using the IEC 61850 System Configuration Description (SCD) file for the project.

DAS Acceptance Test (DASAT)

The DAS acceptance test corresponds to the common site acceptance test (SAT) of a substation protection, automation and control system, but covers to complete testing of the DAS which is distributed in multiple sites. It is the verification of each data and control point and the correct functionality not only of the individual components of the system, but also the communications between the different sites. The site acceptance test is a precondition for the DAS being put into operation.

The DASAT, similar to the FAT is a customer agreed functional tests of the specifically manufactured substation protection, automation and control system, performed with the complete system as installed in the substation.

It is also a subject of agreement between the final user and the system integrator from the point of view of the content of the test plan and the responsibilities of the involved parties.

There are no specific guidelines on what should be included in a DAS acceptance test. Development of such guidelines will be of great help to the industry in order to ensure the completeness of the testing process and reduce the probability for failure of the system when put in service.

Site acceptance testing should be performed using a top-down approach based on a test plan including test scenarios defined as part of the design of the system.

Black box testing methods can be used until any failure of the system for a specific test occurs. White box testing will then be used to determine the reason for the test failure.

One of the main characteristics of site acceptance testing is that all components of the system are available. That requires from the test system the ability to simulate all required analog, binary or other signals required for the testing of any specific substation or electric power system condition that the real system is designed to handle.

The site acceptance test should be based on configuration of all devices using the SCD file for the project.

The final stage of the DAS site acceptance test should be performed as end-to-end testing to ensure that all the wiring between the process and the devices included in the substation protection, automation and control system are properly done.

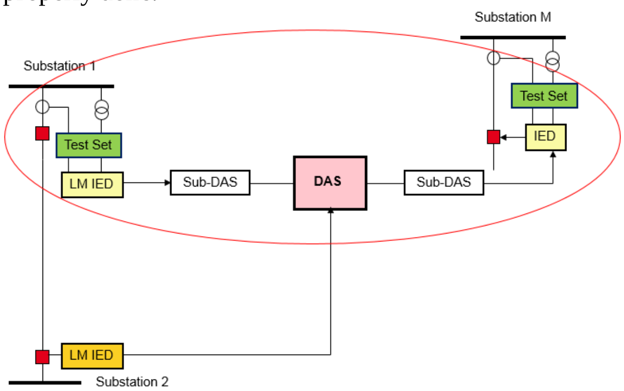

Fig. 6 DAS acceptance test

To compare with the FAT, which is performed off site where the system was assembled and it has to prove that the complete system fulfils the properties specified in the contract between the manufacturer and the user before it leaves the factory, the DAS SAT concludes commissioning and proves that the system fulfils the contract before it goes into operation.

For the end-to-end testing of some distribution automation functions it may be necessary to GPS time synchronize the testing devices at all the sites.

CONCLUSIONS

Testing of Distribution Automation Systems requires good understanding of the functionality and the hierarchy of the system.

Different methods are used for testing of the components of the system, as well as the distributed sub-functions and functions.

Bottom-up testing is used at the initial phases of development and implementation of the system and especially for the acceptance of IEDs to be used at the system monitoring and process control levels of the system.

Black box and top-down testing can be used during the factory and site acceptance testing stages.

End-to-end testing is required for the final acceptance test of the DAS before it can be put in service.